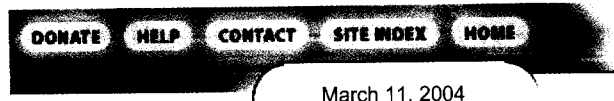


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Improving Survival From Sudden Cardiac Arrest: The "Chain of Survival" Concept

A Statement for Health Professionals From the Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee, American Heart Association.

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Overview

More people can survive sudden cardiac arrest when a particular sequence of events occurs as rapidly as possible. This sequence is 1) recognition of early warning signs, 2) activation of the emergency medical system, 3) basic cardiopulmonary resuscitation, 4) defibrillation, 5) intubation, and 6) intravenous administration of medications. The descriptive device "chain of survival" communicates this understanding in a useful way ([Figure 1](#)). While separate specialized programs are necessary to develop strength in each link, all of the links must be connected. Weakness in any link lessens the chance of survival and condemns the efforts of an emergency medical services (EMS) system to poor results. The chain of survival concept has evolved through several decades of research into sudden cardiac arrest. Effective system interventions have been identified that will allow survivors to remain neurologically intact. While a few urban systems may be approached the current practical limit for survivability from sudden cardiac arrest, most EMS systems, both in the United States and other countries, have defects in their chain. Poor resuscitation rates have been the rule. This statement describes the research supporting each link and recommends specific actions to strengthen the chain of survival.

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The Links in the Chain of Survival

The Early Access Link

The chain of survival begins with early access, in which the patient is helped as quickly as possible. Early access includes the implied component of early recognition. The resuscitation chain is initiated when a medical emergency is recognized and the emergency medical system accessed and activated.¹ The time required for access begins the moment an emergency is recognized, by either the person with symptoms or a witness to the emergency. With sudden cardiac arrest, access time begins at the moment of collapse, and includes recognition of the emergency, the decision to make the call, time spent locating a telephone and emergency number, interrogation of the caller by the emergency dispatcher, and the decision to send an emergency vehicle. The dispatcher may need additional times to route the call to the proper response station or vehicle (call-processing time). Once the responder is notified, ambulance response time begins. Ambulance response time is the interval from receipt of the call by the emergency responder to arrival of emergency personnel at the scene. Additional time may elapse before the responder actually examines the patient. Recognition, call processing, and ambulance response time add seconds, typically minutes, to the critical interval between arrest and initiation of emergency treatment.



Figure 1. Sequence of events in emergency cardiac care is displayed schematically by "chain of survival" metaphor.

The most common approach to shorten the interval between collapse and arrival of emergency personnel has been to acquire more ambulances,^{2,3} which is both expensive and inefficient, especially if the EMS system is established. Studies have shown that after a certain point an increase in the number of ambulances fails to lower response time significantly.⁴ In one model, response time varied inversely as the square root of the number of vehicles per square mile; an 80% increase in the number of vehicles reduced average response time by only 1 minute.⁴ This same 1-minute reduction in average response time could be achieved by greater public awareness and more efficient dispatching systems, and at far less cost.

The early access link can be strengthened through public education, especially persons most likely to witness a cardiac arrest, and by installation of an efficient emergency communication system. Educational and public service programs such as those of the American Heart Association¹ and the American Red Cross⁵ are designed to make the public aware of what to do when cardiac arrest occurs. Participants in classes on cardiopulmonary resuscitation (CPR) and AHA-sponsored schoolsite and worksite training learn the warning signs of heart attack, how to recognize a person in cardiac arrest, and to quickly call the EMS system when a person collapses. Persons who are uninformed about chest pain and respiratory distress may not comprehend signs of an impending cardiac arrest. When a person collapses, such a witness may wait a long time before calling the emergency dispatch center. A witness may telephone neighbors, relatives, or even his or her personal physician before calling the emergency number, as observed in both central London⁶ and rural Iowa.⁷ In Belgium and Holland it is almost the rule to first call the local physician. This poses a problem in terms of early defibrillation because physicians are less likely to carry defibrillators than emergency responders. In Iowa a "phone first" program has been started to achieve immediate notification of the EMS system when a person collapses.⁷ Such educational campaigns may become more widespread. Early access ensures that precious minutes are not wasted at the start of cardiac arrest.

Lack of a three-digit 911 emergency dispatch system (or its equivalent) can produce

confusion and delays because witnesses may call the wrong number, call multiple numbers, or spend time searching for the number. In one community in North Carolina, 85 different emergency numbers are listed in the local telephone book.^{8,9} In contrast, in Seattle, Washington, which has an enhanced 911 system, 90% of 1,271 people interviewed identified 911 as their EMS notification number.¹⁰ Investigators from Minneapolis who performed a before-and-after evaluation of a 911 system¹¹ noted that the percentage of emergency callers who could activate the EMS system in less than a minute rose from 63% before implementation of the system to 82% afterward. The percentage of callers who made only one telephone call to activate the system went from 40% before the 911 system was started to 74% after the system began.

Another study showed that imprecise knowledge of how to notify the emergency system can cause confusion and delays.¹² In this telephone survey, people living in 911 system communities knew the correct number to call 85% of the time; in regional systems with several fire department operating from one dispatching center, people knew the correct number to call only 47% of the time; in systems with a local seven-digit number for a particular fire district, people gave the correct number only 36% of the time. Many people who lived near a 911 area thought 911 was their emergency number; when they mistakenly called 911, delays of 30 seconds to 2 minutes resulted. Establishment of a 911 emergency system is a key step. Given the transient and mobile nature of today's population, a universal access number must be adopted by EMS systems. By 1992 a common emergency telephone number will be introduced in the European community and will cover a population of more than 350 million.

The Early CPR Link

The next link in the chain of survival is early initiation of basic CPR.^{1,13} Basic CPR should be started immediately after cardiac arrest is recognized and should coincide with efforts to gain access to and activate the EMS system. EMS systems should rely on trained citizens rather than emergency responders to initiate CPR. With rare exceptions, initiation of CPR by emergency personnel is too late. Only systems with rapid response times, such as that in Milwaukee, Wisconsin,^{14,15} can employ EMS providers as the primary initiators of CPR.

For almost 3 decades the chest compressions and positive pressure ventilations of standard CPR have helped return pulseless, nonbreathing patients to spontaneous respiration and cardiac perfusion.^{16,17} The value of early CPR is that it can buy time for the primary cardiac arrest patient^{1,13,18-22} by producing enough blood flow to the central nervous system and the myocardium to maintain temporary viability. To do so, however, basic CPR must be started early, and the earlier the better. Initial CPR must be followed by rapid defibrillation, intubation, and administration of cardiovascular medications by EMS personnel.²³ Early bystander CPR is less helpful in resuscitation if EMS personnel equipped with the defibrillator arrive late, or about 8-12 minutes after collapse.²⁴ Recent data from the Belgium Cardio-Pulmonary-Cerebral Resuscitation Registry¹⁸ and Scotland,²⁵ however, suggest some prolonged benefit from bystander CPR even with late arrival of advanced life support personnel. The combination of late CPR (more than 4 minutes) and late advanced life support (more than 12 minutes) is particularly lethal.^{22,24,26} Several researchers have called these time dimensions the resuscitation "failure zone."²⁷

Many reports contain data to compare the survival rates of cardiac arrest victims who receive early CPR (defined as citizen-initiated CPR) with the survival rates of those who receive late CPR (defined as emergency responder-initiated CPR).^{22,24,28,29-42} **Table 1** presents summary data from these studies, including estimated odds ratios for survival. Early CPR usually differs from late CPR by about 4 minutes. In all but one system, researchers observed a positive benefit of early CPR when they compared survival rates between persons who received early CPR and those who received late CPR. The magnitude of this contribution may be

considerable since the odds ratios for improved survival with early CPR can range as high as 11.5 (Table 1). In Milwaukee,^{14,36} the only system in which this benefit was not observed, emergency personnel performed late CPR an average interval of only 2 minutes after early bystander-initiated CPR. Thus the data from Milwaukee simply compare early CPR with even earlier CPR. The similar survival rates for people who received bystander CPR compared with those deprived of bystander CPR are not surprising and provide additional support for the concept of a narrow window of CPR effectiveness.³⁸ The association between early CPR and improved survival appears related to the effect of basic CPR on ventricular fibrillation.^{18,38,43,44} Researchers have observed that when rescuers start CPR early, the patient is more likely to be in ventricular fibrillation when a monitoring unit arrives.⁴⁴

Investigators in King County, Washington, observed that 80% of cardiac arrest victims were in ventricular fibrillation/ventricular tachycardia if they had received early bystander CPR, compared with 68% if they had received delayed CPR.³⁸ In Stockholm, 67% of people in cardiac arrest in whom CPR was started by bystanders were in ventricular fibrillation/ventricular tachycardia, whereas only 45% of persons not given bystander CPR were in ventricular fibrillation/ventricular tachycardia.⁴³ The Belgian Cardio-Pulmonary-Cerebral Resuscitation Registry has reported a 42% prevalence of ventricular fibrillation in cardiac arrest patients who received bystander CPR, compared with 29% in arrest patients who received delayed CPR.¹⁸

These three studies suggest that CPR prolongs the duration of ventricular fibrillation. In addition, they suggest that the presence of ventricular fibrillation operates as a dependent variable rather than an independent variable in analyses of survival data.^{18,22} Victims who receive early CPR are also more likely after electrical shock to convert to a cardiac rhythm associated with restoration of spontaneous circulation.^{22,26,38} In King County, Washington, persons in ventricular fibrillation when EMS personnel arrived has a 37% rate of long-term survival if they were given bystander CPR, compared with 29% if they were not.³⁸ In Houston, 40% of patients with ventricular fibrillation/ventricular tachycardia were discharged from the hospital if they had received bystander CPR, versus 19% for such patients not given bystander CPR.²²

Several approaches ensure the performance of basic CPR by bystanders before emergency responders arrive. The most widely advocated is citizen CPR training. Community-based CPR training programs, endorsed and conducted by the American Heart Association and the American Red Cross, have trained millions of laypersons in CPR.¹ The American Heart Association has suggested that if 20% of adults were trained in CPR, morbidity and mortality from out-of-hospital cardiac arrest might be significantly reduced.⁴⁵ Some communities have actually achieved this level of adult training, despite physician reluctance to "prescribe" CPR training for family members and friends of high-risk patients.^{10,46,47} In the Seattle area, for example, Leonard Cobb and coworkers⁴⁸ have trained over 2 million people. In Minneapolis a survey of 2,310 adults noted that 23% were trained in CPR.⁴⁹

However, there are problems with the concept that a threshold level of citizen training can be "protective." Most people trained in CPR never see an arrest; most people who see an arrest have not been trained in CPR.^{49,50} The Minneapolis survey found that only 10% of the population trained in CPR had witnessed a cardiac arrest⁴⁹ and only 30% of witnesses to a cardiac arrest had been trained in CPR. Only 19% of persons trained in Minneapolis continued retraining every year.⁴⁹ This figure nearly duplicates that in a report by Gombeski,⁵⁰ who noted that only 21% of their trainees returned for 1-year retraining.

Other data, however, suggest a more positive picture.⁵¹⁻⁵⁴ Eisenberg et al⁵¹ observed that some knowledge of CPR techniques is so prevalent that many citizens attempt CPR without formal training. In addition, they perform CPR despite

a high prevalence of disagreeable physical characteristics (the presence of saliva, blood, or emesis) encountered during performance of bystander CPR.⁵² Cobb et al^{53,54} observed that outcomes for CPR by untrained citizens is similar to outcomes for trained laypersons. The Belgian Cardio-Pulmonary-Cerebral Resuscitation Registry has noted that the quality of bystander CPR is difficult to evaluate.⁵⁵ In Belgium the most common bystander CPR errors were omission of mouth-to-mouth ventilations, which occurred 46% of the time, and omission of chest compressions, which occurred 17% of the time.⁵⁵ Outcomes were significantly better when rescuers performed both ventilations and chest compressions, compared with ventilations alone or compressions alone.⁵⁵

Table 1. Controlled Studies of Survival (Discharged Alive) From Out-of-Hospital Cardiac Arrest: Bystander Cardiopulmonary Resuscitation Compared with Late Cardiopulmonary Resuscitation

Location/System	Witnessed arrest	Rhythm	Number of patients	Discharged alive (n)	Odds ratio*
1. Oslo, Norway ²⁸ EMTs only	Not reported	Not reported	Bys CPR=75 Late CPR=556	36% (27) 8% (43)	6.7
2. Birmingham ²⁹ Paramedics only	Implied yes	VF or VT	Bys CPR=7 Late CPR=12	86% (6) 50% (6)	6.0
3. Seattle ³⁰ EMTs and paramedics	76% overall witnessed	VF only	Bys CPR=109 Late CPR=207	43% (47) 21% (43)	2.9
4. Winnipeg ³¹ EMTs only	Not reported	VF or VT	Bys CPR=65 Late CPR=161	25% (16)	6.2
5. Iceland ³² EMTs only	Not reported	All rhythms	Bys CPR=38 Late CPR=84	42% (16) 2% (2)	11.5
6. Vancouver ³³ EMTs and paramedics	77% overall witnessed	All rhythms	Bys CPR=43 Late CPR=272	21% (9)	4.0
7. Los Angeles ³⁴ Paramedics	41% overall witnessed	All rhythms VF only	Bys CPR=93 Late CPR=150 Bys CPR=45 Late CPR=70	22% (20) 5% (7) 27% (12) 6% (4)	5.6 6.0
8. King County ¹³ EMTs and paramedics	Not reported	All rhythms	Bys CPR=108 Late CPR=379	23% (25) 2% (45)	2.2
9. Pittsburgh ³⁵ Paramedics	Not reported	VF/VT only	Bys CPR=25 Late	24% (6) 7% (4)	4.3

				CPR=59		
10.	Milwaukee ³⁶ EMTs and paramedics	Witnessed only	All rhythms Coarse VF	Bys CPR=1,248 Late CPR=252 Bys CPR=628 Late CPR=151	15% (182) 15% (38) 24% (148) 23% (35)	1.0 1.0
11.	Michigan/Ohio ³⁷ communities (EMTs and paramedics)	Not reported	All rhythms	Bys CPR=472 Late CPR=1,367	13% (56) 5% (64)	2.7
12.	King County ³⁸ EMT-Ds and paramedics	Both Witnessed only	All rhythms All rhythms	Bys CPR=726 Late CPR=1,317 Bys CPR=579 Late CPR=718	27% (196) 13% (177) 32% (186) 22% (158)	2.4 1.7
13.	York/Adams, Pa. ³⁹ EMTs and paramedics	Witnessed only	VF only	Bys CPR=157 Late CPR=225	22% (34) 6% (13)	4.5
14.	Tucson, Ariz. ⁴⁰ EMTs and paramedics	Witnessed only	All rhythms	Bys CPR=65 Late CPR=130	20% (13) 9% (12)	2.5
15.	West Yorkshire ⁴² Ambulance personnel	Not reported	All rhythms	Bys CPR=47 Late CPR=50	15% (7) 8% (4)	2.0
16.	Belgium ⁴¹ Ambulance Personnel	Not reported	All rhythms	Bys CPR=985 Late CPR=2,036	10% (98) 5% (109)	1.9
17.	Houston ²² EMTs and medics	Both	Unmonitored VF/VT	Bys CPR=53 Late CPR=133	30% (16) 14% (19)	2.1

EMT, emergency medical technician; EMT-D, emergency medical technician trained to defibrillate; VF, ventricular fibrillation; VT, ventricular tachycardia; Bys, bystander; CPR, cardiopulmonary resuscitation.

*Odds ratio is not a simple ratio of survival rates. It is calculated as the odds of surviving with bystander CPR (number discharged alive divided by number who die) divided by the odds of discharge alive for people who received late CPR (number discharged alive divided by number who die).

Another approach to early CPR is the concept of targeted CPR training.^{10,53,54,56-59} Such programs are for persons who have an increased likelihood of having to perform CPR, including middle-aged persons, residents and staff of senior centers, survivors of myocardial infarction, and family members of persons identified as

having cardiac arrest risk factors. These programs are slowly becoming more widespread and represent an important change in the focus of CPR training. Much CPR training in the United States focuses on the young, especially school-age children and young adults,⁵⁷ who are easy to train and show energetic interest. However, they are not likely to witness a cardiac arrest or to take a CPR course. They do, of course, become the "future" performers of CPR as they enter the age group where risk increases. Cardiac arrest victims are typically aging men, who live at home^{6,18,60} and are usually poorly educated and nonprofessional.⁶¹ In King County, Washington, the average age of cardiac arrest patients is 65 years; 77% of cardiac arrests happen at home, and 75% of the victims are men.^{60,62} Therefore, persons with the highest likelihood of witnessing a cardiac arrest and being called upon to perform CPR are those living with or closely associated with middle-aged men. Regardless of age, the prognosis for persons resuscitated from cardiac arrest, even the elderly (those over 70 years old), is excellent.^{63,64} Unfortunately, few middle-aged women in the United States have received formal CPR training, and those who have received training seldom live with high-risk patients.^{10,11} In one survey of people trained to perform CPR, only 7% lived with family members known to have heart disease.¹⁰

A final method to achieve early CPR is dispatcher-assisted CPR instruction, programs in which emergency telephone dispatchers offer CPR instructions to persons who call to report a cardiac arrest.^{51,54-67} Delivery of instructions and performance of a complete CPR cycle of 15 chest compressions and 2 ventilations can be accomplished in 3-4 minutes,^{51,65,67} even by persons who have never received CPR training. Telephone instruction also improves the quality of CPR performed by persons with prior CPR training in manikin simulations.^{22,67} Panicked bystanders can be calmed and directed by dispatchers and encouraged to perform CPR, despite their alarm at the sudden sight of a loved one who is cyanotic and breathless. With this program, plus other educational efforts, the percent of cardiac arrests in which CPR was initiated by bystanders in King County, Washington, has increased from 30% in 1980 to 60% in 1988 (unpublished data).

The Early Defibrillation Link

The purpose of early defibrillation is to reestablish a normal spontaneous rhythm in the heart. Several new approaches can help achieve early defibrillation:

- Automated defibrillators used by the first responding emergency personnel
- Automated defibrillators used by community responders, that is, persons whose usual occupation or training does not require responding to emergencies.
- Home defibrillation programs for high-risk patients
- Transtelephonic defibrillation

The rationale for early defibrillation emerges from data that demonstrate that almost 85% of persons with ambulatory, out-of-hospital, primary cardiac arrest experience ventricular tachyarrhythmias during the early minutes after collapse.

⁶⁸ In one report 157 ambulatory (not hospitalized) patients experienced fatal arrhythmias during continuous cardiac monitoring.⁶⁸ The initial dysrhythmia in 62% of patients was ventricular tachycardia that quickly evolved to ventricular fibrillation, in 8% the dysrhythmia was primary ventricular fibrillation, and in 13% it was torsades de pointes. The duration of the ventricular tachycardia that preceded the ventricular fibrillation ranged from a few seconds to several minutes. This study involved a select population of patients who had some indication for ambulatory cardiac monitoring. Nevertheless, the rhythms they experienced are probably representative of the usual initial rhythms of the sudden cardiac arrest victim.

In prehospital studies, the rhythm of arrest cannot be identified until emergency

personnel arrive with a defibrillator/monitor, 4-8 minutes later. In these studies the percent of people in ventricular tachyarrhythmias was lower, at 60% or less.^{22,62} Most eventual survivors emerge from the group of people who remain in ventricular fibrillation when emergency personnel arrive. For example, in King County, Washington, over 92% of cardiac arrest survivors were from this group,⁶² and over 80% in Houston.²²

Additional evidence about the importance of early defibrillation comes from cardiac arrest experiences in supervised cardiac rehabilitation programs. On the rare occasion when a person in such a program experiences cardiac arrest, it is witnessed, CPR is started immediately, and defibrillation is performed within minutes. Fletcher and Cantwell⁶⁹ reported five cardiac arrests in a medically supervised exercise program; all were resuscitated. Haskell⁷⁰ reported that among 13,570 patients in 30 exercise centers, 50 cardiac arrests occurred and 42 (84%) were resuscitated. Hossack and Hartwig⁷¹ observed 2,464 people in a supervised cardiac rehabilitation program over a 13-year period. In this group 25 men suffered a cardiac arrest, and all 25 (100%) were successfully resuscitated. Van Camp and Peterson⁷² summarized the experience in 167 cardiac rehabilitation programs; 21 cardiac arrests occurred, and personnel resuscitated 18 (86%) without neurologic sequelae. The type of rhythm at arrest in these series was not reported, but sudden arrest during exercise suggests that the large majority of these patients were in ventricular fibrillation. Overall, of 101 cardiac arrests in these reports, staff members resuscitated 90 (89%) of the victims. This is the highest survival rate reported among defined population groups, and it confirms the value of immediate efforts in early CPR and defibrillation.

In England, general practitioners, the most frequent responders to patients with chest pain and cardiac arrest, have observed that early defibrillation alone produces successful resuscitations.⁷³ Many patients in Britain call their general practitioner during the early stages of a myocardial infarction. About 5% of these patients experience a cardiac arrest after the physician arrives.^{74,75} The British Heart Foundation donated 78 defibrillators to 25 general practices and reported on the experiences after 1 year.⁷³ A total of 19 patients suffered cardiac arrest in the presence of a general practitioner who had a defibrillator: 13 (68%) were in ventricular fibrillation, nine were successfully resuscitated outside the hospital, and six were discharged from the hospital.⁷³

In the earliest prehospital programs,^{33-35,42,76-86} only paramedics provided defibrillation. In most studies of paramedic-only systems, the time between collapse and arrival of paramedics averaged more than 12 minutes. These programs therefore generally provide what is more correctly termed *late defibrillation*.

Consequently, the reported survival rates for these systems have been modest, ranging from 7% to 18% for all rhythms.⁸⁷ Researchers in the early 1980s demonstrated the ability of personnel less well trained than paramedics, namely, emergency medical technicians (EMTs), to successfully use defibrillators.⁸⁸⁻⁹¹ Early defibrillation programs implemented for firefighters and minimally trained EMS first responders spread slowly, more often because of implementation barriers and administrative inertia than from doubt of clinical efficacy.^{92,93}

The proposals to allow less well trained emergency personnel to operate defibrillators initially provoked controversy, but most concerns have since disappeared. Conceptually, early defibrillation programs represented the transfer of what was a medical act – diagnosis of the rhythm and operation of a defibrillator – into the hands of nonphysicians. Some authorities accepted the transfer of skills to paramedics. However, many authorities hesitated to permit defibrillation by less well trained emergency personnel. Rational reasons for this hesitancy vanished by the late 1980s with widespread acceptance of the principle of early defibrillation^{1,20,23} and the success of automated external defibrillators.^{94,95} Regrettably, in Germany, France, Japan, and other countries, medicolegal factors still prevent implementation

of early defibrillation programs by nonphysicians.

The principle of early defibrillation holds that the professional rescuer who arrives first at the scene of a cardiac arrest should carry a defibrillator and be trained to operate it.^{1,20,23} With few exceptions, the defibrillator should be automated and external.^{93,94,96-102} Automated external defibrillators are highly accurate^{98,99,101-103} and eliminate the need for training in the complex skills of rhythm recognition. The operator simply attaches the defibrillator's adhesive electrodes to the chest of the person thought to be in cardiac arrest. When activated by a single control, the device analyzes the rhythm, and if ventricular fibrillation or tachycardia is present, the device either charges and delivers a shock (automatic devices) or indicates to the operator that a shock is needed (semiautomatic, or shock-advisory, devices).^{104,105} With shock-advisory devices, the operator delivers the shock by pushing a second control.^{104,106} This simplicity of operation decreases the time and expense of initial training and continuing education and markedly increases the number of persons who can operate the devices. Clinical studies also show that systems using automated defibrillators can deliver the first shock up to 1 minute faster than conventional defibrillators because of the speed with which these devices can be attached and with which they operate.^{98,99}

Each year more communities in the United States allow the use of both automated and conventional defibrillators by EMTs and by less trained personnel called *first responders*, a term that refers specifically to persons who have completed a 40-hour course. The term can refer to a much larger group of public safety employees, including firefighters, ambulance personnel, part-time emergency volunteers, police officers, highway patrol personnel, security guards, merchant marine sailors, and airline, railroad, and other public transportation vehicle crews.

Automated defibrillators are used by first responders around the world,^{107,108} with early defibrillation programs in Scotland,²⁵ Denmark,¹⁰⁹ England,⁶ West Berlin,^{107,108} Norway,¹¹⁰ Sweden,⁴³ Australia,¹¹¹ Singapore,¹¹² Finland, Belgium, and many other countries. By 1988, 37 states in the United States had passed legislation permitting early defibrillation by EMTs and, in some states, basic first responders.¹¹³ An additional 10 states planned to initiate similar programs in 1989.¹¹³ Many communities permit first-responder (usually firefighter) defibrillation, including Houston; Dallas; Memphis; San Francisco; Salt Lake City; Seattle; King County, Washington; and Eugene-Springfield, Oregon.^{102,114-116} The International Association of Fire Chiefs has endorsed this concept and has started an initiative called *RapidZap*,¹¹⁴⁻¹¹⁶ which has the goal of equipping all fire department emergency response vehicles with automated defibrillators by the year 2000. The fire chiefs adopted this concept not only out of concern to provide effective care for all citizens but also concern for the well-being of their personnel. Surveys of firefighter deaths have noted that the majority of on-duty deaths are due to sudden cardiac arrest.^{117,118}

How effective are programs in which defibrillators are given to EMTs and first responders? Variable degrees of success have been observed in clinical studies thus far. The published survival rates for systems whose prehospital response teams consist only of EMTs trained in defibrillation range from 6% to 26% for patients found to be in ventricular fibrillation.^{43,88,89,119-121} The most important comparison, however, is between the survival rate in communities before and after institution of an early defibrillation program. In suburban communities in King County, Washington, for example, the survival rate for patients in ventricular fibrillation increased from 7% to 26%.⁸⁸ Similarly, in communities in Iowa it increased from 3% to 19%.⁹⁰ In southeastern Minnesota the survival rate was 4% without EMT defibrillation and 17% with such a program,¹¹⁹ whereas in northeastern Minnesota the survival rate was 2.5% without and 9.9% with EMT defibrillation.⁷⁷ When an early defibrillation program was started in certain Wisconsin communities, the survival rate rose from 3.6% to 6.4% for all cardiac arrests and was 11% for patients initially noted to be in ventricular fibrillation (*Table 2*).¹²² It is

important to note that these programs should maintain and increase initial improvements in survival rates as experience and competency improve over time.

Table 2. Effectiveness of Early Defibrillation Programs: Survival From Ventricular Fibrillation

Location	Before early defibrillation	After early defibrillation	Odds ratio for improved survival*
King County ⁸⁸	7% (4/56)	26% (10/38)	4.6
Iowa ⁹⁰	3% (1/31)	19% (12/64)	6.9
Southeastern Minnesota ¹¹⁹	4% (1/27)	17% (6/36)	5.2
Northeastern Minnesota ⁷⁷	3% (3/118)	10% (8/81)	4.2
Wisconsin ¹²²	4% (32/893)	11% (33/304)	3.3

*The odds ratio is not a simple ratio of survival rates. It is calculated as the odds of surviving after an early defibrillation program (number who live divided by number who die), divided by the odds of surviving before an early defibrillation program (number who live divided by number who die).

Home and community responder defibrillation programs. Two other techniques advocated to help achieve early defibrillation are home defibrillation programs for high-risk patients and early defibrillation by community responders. Community responders include public safety workers or laypersons who may have a perceived duty to respond to an emergency.^{96,123-125} Although these approaches have been under evaluation for several years, their specific effects on community-wide survival rates from cardiac arrest have not been determined.¹²³ Moore et al¹²⁶ observed that of 95 survivors of ventricular fibrillation, only 63 (66%) were eligible for a home defibrillator, and only 38 of 47 (81%) persons approached agreed to participate. This suggests that approximately half (0.66x0.81) of ventricular fibrillation survivors would receive the device and appropriate training. McDaniel et al¹²⁷ also experienced recruitment problems in a similar home-defibrillation study. Only 8% of survivors of acute myocardial infarction participated in their study. The reasons for low participation included patients living alone, patients discharged to nursing homes, patients having no telephone, resuscitation considered medically inappropriate, implantation of automatic internal defibrillators, residence outside the study areas, no perceived chance of repeat cardiac arrest, religious objections, and elimination from the study at the demand of personal physicians.^{126,127}

Nevertheless, enough experience has accumulated to establish the feasibility of training family members of high-risk patients and community responders to use automated defibrillators.¹²⁶⁻¹²⁹ Despite some decline in skill retention and performance, family members and lay responders can remember most training and retain the skill for up to 1 year and can use the device at the moment of cardiac arrest of a family member or coworker.¹²⁸

So far, only limited clinical experience demonstrates the practicality and effectiveness of home and community responder defibrillation programs. Chadda et al¹³⁰ reported a case series of 30 patients with witnessed cardiac arrest. Lay persons used automated defibrillators before the arrival of trained emergency personnel. Rescuers resuscitated eight of these patients to an organized rhythm associated with spontaneous circulation. Five were discharged from the hospital. Swenson et al¹³¹ reported a series of 48 high-risk patients where the research team trained family members to operate automated defibrillators. Five cardiac arrests occurred in this series. The trained home responders used the automated defibrillator four times, and three patients had successful restoration of circulation.

Researchers from King County, Washington, however, have experienced less positive results with home¹³² and community responder defibrillation.¹²⁸ Eisenberg et al¹³² placed automated defibrillators in the homes of 59 persons who had survived prehospital cardiac arrest. Ten cardiac arrests occurred; home responders used the device in six patients. Only two patients were in ventricular fibrillation. One of the two patients was resuscitated but survived only a few months with residual neurological deficits. In another King County study, researchers placed 14 automated defibrillators in a variety of community settings and trained 146 lay people working in those settings to operate the device.¹²⁸ Only three cardiac arrests occurred. Recognition and operation errors prevented proper attachment and use of the defibrillator for all three patients. However, manufacturers have since developed simpler, lighter, and more sophisticated automated defibrillators with more user-friendly protocols and simpler placement of electrode pads. Researchers may achieve better results if they conduct future studies with the currently available devices.

In contrast, several other studies have achieved better results when automated defibrillators were placed with community responders. Weaver et al¹³³ trained 160 security personnel at the 1986 World's Exposition in Vancouver, British Columbia, to operate an automated defibrillator in the event of a cardiac arrest. There were five cardiac arrests among 22.1 million visitors. Rescuers used automated external defibrillation on each victim, two of whom were in ventricular fibrillation. Automated external defibrillation was successful in both patients, and sustained circulation returned. Both patients were moving and semiconscious by the time emergency personnel arrived. In England researchers placed automated external defibrillators on long-distance aircraft of an international air carrier.¹³⁴ This preliminary study ceased when another company purchased the air carrier, but senior cabin attendants trained with great enthusiasm. Several other airlines are likely to implement similar programs in the near future. In London researchers trained conductors at several British Rail stations to operate automated defibrillators. There are early anecdotal reports of successful resuscitation.¹³⁴ High-risk or isolated industrial settings represent another interesting target group for implementation of early defibrillation programs. Safety personnel have, for example, placed and successfully used automated external defibrillators on oil platforms in the North Sea, at electricity plants, and on passenger cruise ships and merchant marine vessels.^{95,100,110,130}

Future research will help establish the exact role of these innovative approaches. However, clinical evidence is insufficient to support widespread home placement of automated external defibrillators with high-risk patients. The evidence is more encouraging for busy public places such as airports, railway stations, convention centers, major hotels, and large public assemblies, and high-risk or remotely located industries with trained safety personnel.

Transtelephonic defibrillation. Transtelephonic defibrillation is a recently introduced method to provide early defibrillation.¹³⁵⁻¹³⁷ However, it should not be classified with automated external defibrillation. In transtelephonic defibrillation a trained family member or other companion attaches adhesive monitor/defibrillator pads to a person with cardiac complaints or in cardiac arrest. The defibrillator pads are attached through cables to a home unit that then transmits the rhythm by telephone circuitry (either hard-wired or cellular) to a remote base station. Emergency personnel at the base station interpret the rhythm and make the decision to deliver a shock. Base station controls can be used to charge the home defibrillator unit and deliver the shock. A two-way speaker phone provides simultaneous voice communication between the home and the base station. Researchers have confirmed this concept of remote defibrillation in hospital settings.^{136,137} Physicians have attached the device to patients in one hospital location (usually a coronary care unit for elective cardioversions) and operated it from another. This approach offers potential advantages over automated external

defibrillators when used in the home setting, including two-way voice communication, automatic dialing of 911, and transfer of decision making to emergency personnel.¹³⁸ Although approved for clinical use, clinical experience confirming the effectiveness of prehospital transtelephonic defibrillation is limited to a single patient, widely reported in the lay press.¹³⁹ It remains to be seen whether transtelephonic defibrillation will be considered cost-effective and put to major practical use. This doubt is especially valid since clinicians have already confirmed the ability of automated external defibrillators to interpret rhythms and deliver shocks satisfactorily.

The Early Advanced Cardiac Life Support Link

In many instances CPR and defibrillation alone do not achieve or sustain resuscitation. The unique interventions of the early advanced cardiac life support link – endotracheal intubation and intravenous medication – are necessary to further improve the chances of survival. In the United States, paramedics provide advanced cardiac life support for prehospital cardiac arrest patients.¹⁴⁰ Paramedics receive 1,000-3,000 hours of classroom training and field instruction and can provide intubation, defibrillation, and intravenous medications.

EMS systems in other countries provide many models of care. Some are more innovative than those used in the United States. There are no paramedics as such in Europe. Ambulance personnel in the first responding units are sometimes provided with extensive training, which may be from 400 to 500 hours. In Oslo, for example, ambulance personnel (equivalent to US basic EMTs) are taught to perform endotracheal intubation. In Holland a registered nurse who can operate a manual defibrillator arrives on more than 80% of the first-responding ambulances. Other systems, such as that in Göteborg, Sweden, use a second responding unit manned by specially trained nurses on 24-hour duty, similar to a US paramedic unit. Physician-manned mobile coronary care units are also common.

In other locations, especially in France, Israel, and Germany, and to a much lesser extent in England, Australia,⁴² and Finland, emergency physicians (called *ambulance doctors*) provide advanced cardiac life support.¹⁰⁷ They respond in specially equipped vehicles, known as *doctor-manned ambulances*. Systems in the United States, however, abandoned programs with physicians or nurses on ambulances years ago because physician-staffed ambulances in the United States were considered an inefficient use of physician resources. In addition, paramedics can perform the same functions with comparable effectiveness.¹⁴⁰

Physician-staffed ambulances in Europe, however, may well be more cost-effective than they are in the United States, depending on relative operating costs, professional salaries, population density, and combined services such as air rescue. In Norway, for example, nine doctor-ambulance units combined with helicopter services respond effectively to about 4,500 patients a year in a population service area of 4 million people. These units depend on public subscriptions and have been quite popular. In Australia several states and localities use a single-layer ambulance response. The ambulance training, however, includes both early defibrillation and administration of up to 20 drugs (but not intubation). The guiding principle in all systems, no matter how organized, is to provide the necessary treatment to the patient in the most timely and cost-effective manner.

Table 3. Range of Rates of Survival to Hospital Discharge for All Cardiac Arrest Rhythms and for Ventricular Fibrillation by System Type*

System type	Survival: all rhythms	Weighted average	Survival: ventricular fibrillation	Weighted overages for survival
EMT/AMB only	2-9%	5%	3-20%	12%
EMT/AMB-D	4-19%	10%	6-26%	16%

Paramedics/doctors only	7-18%	10%	13-30%	17%
EMT/AMB+paramedics/doctors	4-26%	17%	23-33%	26%
EMT/AMB-D+paramedics/doctors	13-18%	17%	27-29%	29%

EMT/AMB, Basic emergency medical technicians or ambulance personnel.^{31,33,77,78,88,90,122,142,152,153}

EMT/AMB-D, Emergency medical technicians or ambulance personnel who are trained to defibrillate.^{77,88,90,119,122}

Paramedics/doctors only, Ambulance vehicles staffed with paramedics or doctors.^{6,33-35,76-86}

EMT/AMB+paramedics/doctors, Ambulance vehicles staffed with basic emergency medical technicians or ambulance personnel plus second response vehicles staffed with paramedics or doctors.^{33,38,39,101,154-158}

EMT/AMB-D+paramedics/doctors, Ambulance vehicles staffed with emergency medical technicians or ambulance personnel who are trained to defibrillate, plus second response vehicles staffed with paramedics or doctors.^{89,143}

*Data from 31 locations.

Defibrillation and advanced cardiac life support. Observers classically have considered defibrillation a part of advanced cardiac life support care. Now, however, early defibrillation is a separate link in the chain of survival. EMTs and other early responders¹¹³ share this skill with paramedics, physicians, and nurses. Still, in view of the simultaneous therapies employed during a resuscitation attempt, it is difficult to separate the value of defibrillation from the value of intubation and intravenous medications.

What incremental benefit can be derived from these advanced procedures compared with defibrillation alone? Evidence from different locations, with different emergency response systems, sheds some light on this question. Differences in survival rates exist between a system that provides only early defibrillation and early advanced cardiac care. These differences may indicate the additional benefit of advanced cardiac life support. In Iowa, for example, small communities that have provided early defibrillation without prehospital advanced cardiac life support care have achieved a ventricular fibrillation survival rate of 19%.⁹⁰ Meanwhile, suburban King County, Washington, which uses a tiered system (early defibrillation crews followed by advanced cardiac life support crews), has achieved an even greater survival rate. This system reports a 29% survival rate for patients with witnessed ventricular fibrillation arrest.⁸⁹ Emergency personnel resuscitated about 30% of persons who survived with defibrillatory shocks alone, either from emergency medical technicians trained to defibrillate (EMT-Ds) or from paramedics. These people did not require subsequent intubation or intravenous medications.¹⁴¹

The average survival rate for EMT-D-only systems has been 16%^{43,90,119,120,142} (see [Table 3](#)). This rate refers to patients in witnessed cardiac arrest and in ventricular fibrillation. This is significantly lower than the average ventricular fibrillation survival rate of 29% in combined EMT-D and paramedic systems.^{89,143} Paramedic-only systems have an average survival rate of 17%, almost exactly the same survival rate as EMT-D-only systems.^{33-35,76-86} Paramedic-only and EMT-D-only systems average the same survival rate for a specific reason. In paramedic-only systems all advanced cardiac life support interventions (defibrillation, intubation, and administration of medications) are performed, but performed late. Only basic CPR and defibrillation are performed in EMT-D-only systems, but these interventions are performed much earlier.

These observations confirm that a considerable portion of all survivors are alive because of early defibrillation alone. These data also imply the important additional value of intubation and intravenous medications. Researchers think that these

interventions not only promote return of spontaneous rhythm and circulation but also stabilize and maintain patients during the immediate postresuscitation period. Ventricular fibrillation survival rates in EMT-D-only systems ([Table 3](#)) can be compared with survival rates of tiered EMT-D/paramedics systems. Such a system comparison hints at the relative value of these two system types. The table shows that EMT-D systems alone resuscitate about half of all potential ventricular fibrillation survivors.

Systems already staffed with paramedics or, as in Europe, with doctor-manned ambulances should consider the addition of a basic EMT- or ambulance-defibrillation program, which may significantly increase the ventricular fibrillation survival rate. However, no system should delay the start of an early defibrillation program because of the absence of paramedics or doctor-manned ambulances. In fact, some paramedic-only⁴² or doctor-manned systems^{73,111} have such long response times and such poor outcomes that they may be abandoned in favor of or supplemented by early automated defibrillation.

Resources may prevent establishment of a tiered response system that includes first-responder defibrillation as well as paramedics. In these circumstances, first-responder defibrillation, rather than paramedics alone, is probably the most efficient method to improve survival from cardiac arrest. For locations without an effective method of rapid delivery of prehospital defibrillation, the rational approach is to start with first-responder automated defibrillation. Innovative leaders in such locations as Japan,¹⁴⁴ Scotland,²⁵ Singapore,¹¹² England,⁶ Norway,¹¹⁰ Australia,^{111,145} Sweden,⁴³ and Hong Kong¹⁴⁶ have all abandoned inappropriate plans to institute or continue paramedic systems. Instead, these programs are going directly to the more efficient and more effective approach of automated defibrillation.

Commentary

What is the maximum practical survival rate? The number of people resuscitated from sudden cardiac death by emergency personnel is not known. Nor is it known how many people can be resuscitated with a reasonable chance of surviving and remaining neurologically intact. Cardiac disease, in general, is the single greatest cause of death in the United States.^{22,147} For the adult American population, epidemiologists have estimated the annual incidence of out-of-hospital sudden cardiac arrest at about 1 in 1,000 per year.¹⁴⁷ Other statistics from the American Heart Association are often quoted: 1.5 million "generic" heart attacks per year in the United States, of which 25%, or 350,000-400,000, die out of the hospital.¹⁴⁷ Though no national averages are available on the proportion of people who survive out-of-hospital cardiac arrests, current estimates suggest that no more than 1-3% of victims live to be discharged from the hospital. The true percentage is probably even less.¹⁴⁸

It could be argued that the highest survival rates currently reported for out-of-hospital cardiac arrests are a reasonable target for all locations. While achievements of such survival rates are not practical in every community, this approach does expose the gap between what a community does achieve and what is possible. The highest published rates come from sophisticated urban/suburban systems like King County, Wisconsin,⁶² and Seattle.¹⁴³ Both can be described as mature EMS systems. Over the past 10-15 years these locations established strong links in the chain of survival. The annual survival rates for King County, Washington, from 1976 through 1987, fluctuate between 15% and 20% for all cardiac arrests and 25-30% for all patients in ventricular fibrillation ([Figure 2](#)). These overall survival rates, however, have remained moderately stable despite a number of system interventions, such as EMT defibrillation with manual defibrillators,⁸⁸ EMT defibrillation with automated defibrillators,⁹⁸ dispatcher-assisted CPR,⁵¹ and transcutaneous pacing.¹⁴⁹ Therefore, this level of ventricular fibrillation survival may represent the practical limits for prehospital emergency care.